



Naturally Occurring Mini-Outbursts at Comet Tempel 1

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Comets are...

- Small, usually around 5 km across
- Tend not to be spherical
- Composed of a mix of ice and dust
- Usually on very eccentric orbits
- When close enough to the sun, the ices sublime from the nucleus and form a cloud of gas and dust called the coma
- The gas and dust are then swept away from the coma forming two tails that extend for many million kilometers

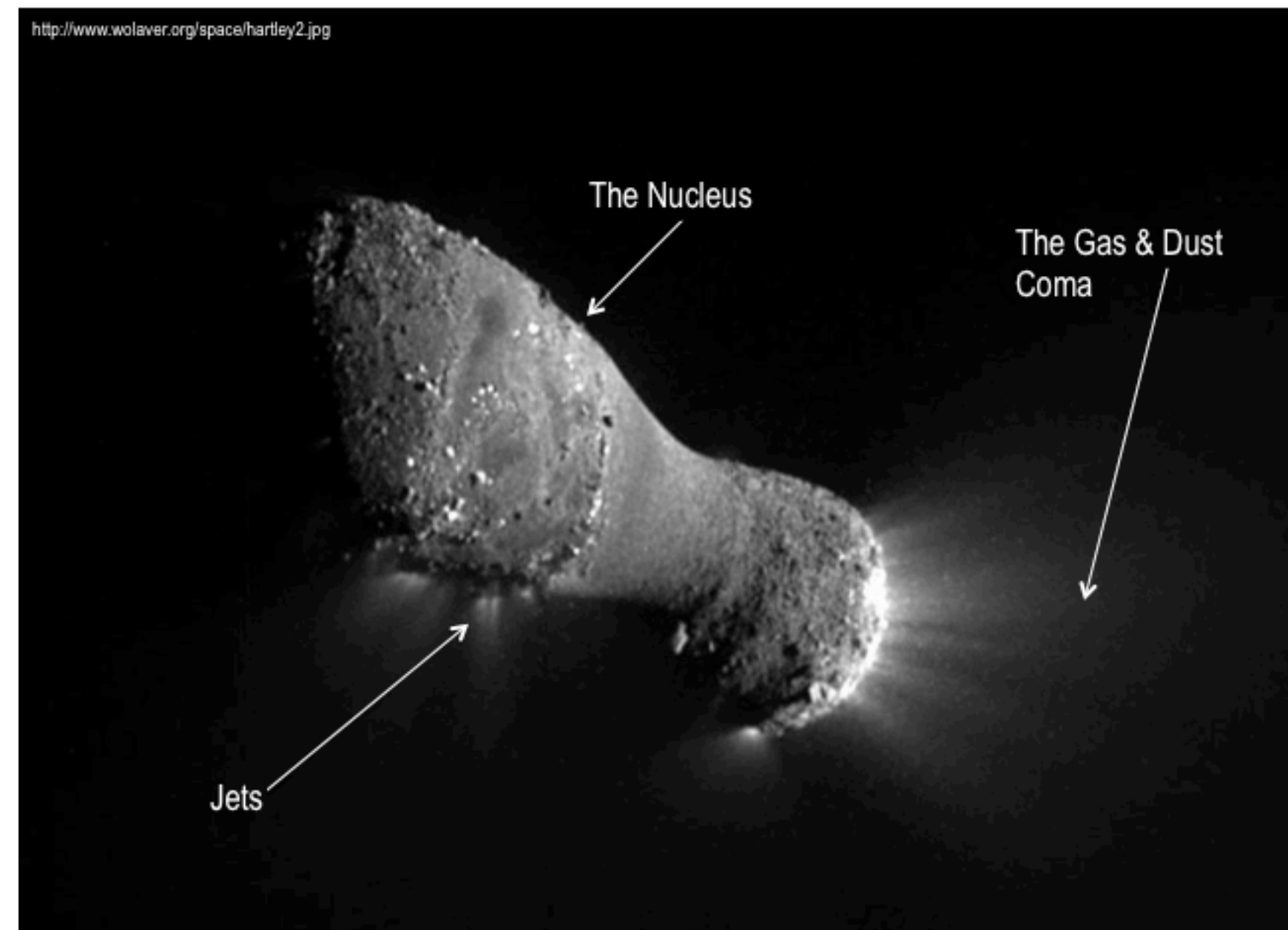


Fig. 1: Nucleus and inner coma of comet Hartley 2

Why study comets?

- Comets are leftovers from the formation of the Solar System
- Comets are well preserved, making them great probes of the Solar System's early years
- By understanding comets we can gain a better picture of how Earth formed and acquired its water and organics

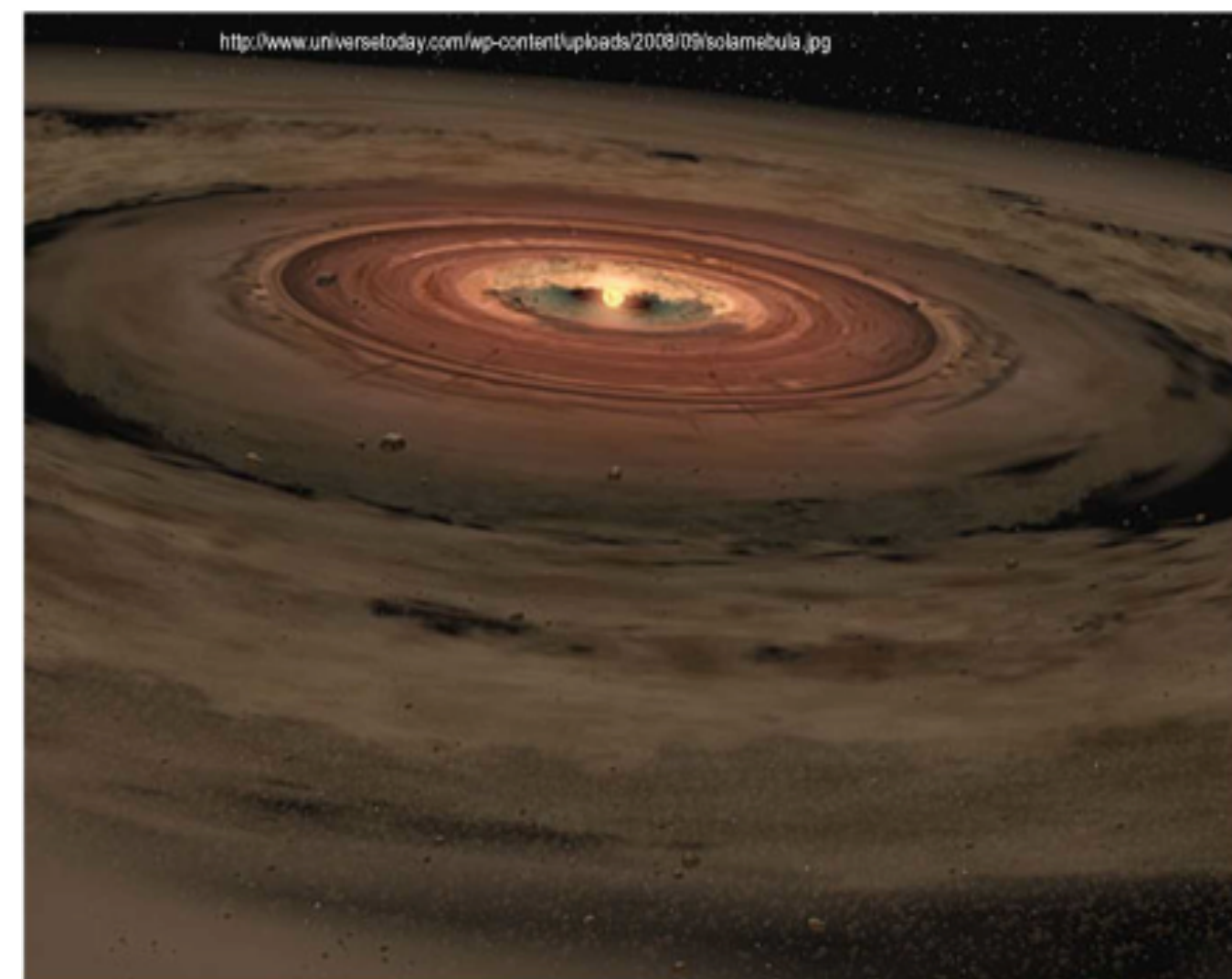


Fig. 2: Artists impression of the early Solar System

The Deep Impact Mission

- Deep Impact encountered comet Tempel 1 on July 4th 2005
- The flyby spacecraft carried 2 visible imagers (HRI-Vis & MRI) and 1 infrared spectrometer (HRI-IR)
- The impactor spacecraft carried 1 visible imager (ITS)
- The impactor had a mass of 372 kg and collided with Tempel 1 at 10.3 km/s (A'Hearn et al., 2005)
- This collision delivered 19 GJ of energy, the equivalent of 4.5 tons of TNT (A'Hearn et al., 2005)
- Data was collected both pre and post-impact



Fig. 3: The Deep Impact spacecraft

Deep Impact's Infrared Spectrometer

- HRI-IR operates between wavelengths of 1.05 and 4.85 microns, a region where H₂O, CO₂, CO, and organic molecules have emission lines
- Has a minimum spectral resolving power ($\lambda/\Delta\lambda$) of 200
- Is a long-slit spectrometer, so each frame has a spatial dimension (512 pixels, unbinned) and a wavelength dimension (1024 pixels, unbinned)
- Binned pixels have a FOV of 10⁻¹⁰ steradians
- The middle third of the slit is covered by an anti-saturation filter (ASF) to prevent the nucleus from saturating the detector
- Scans were used to gain a second spatial dimension

Outbursts at Tempel 1

- 12 were observed by Deep Impact (A'Hearn et al., 2005, McLaughlin, private communication)
- 1 was observed by the Hubble Space Telescope and Calar Alto observatory (Feldman et al., 2007, Lara et al., 2006)
- Large outbursts eject ~10⁶ kg of material (Belton et al., 2008)
- Outbursts occur at a rate of ~0.3 per day, with some rotational phases more likely to produce an outburst than others (Farnham et al., 2007)
- These outbursts occur too frequently to be the result of impacts

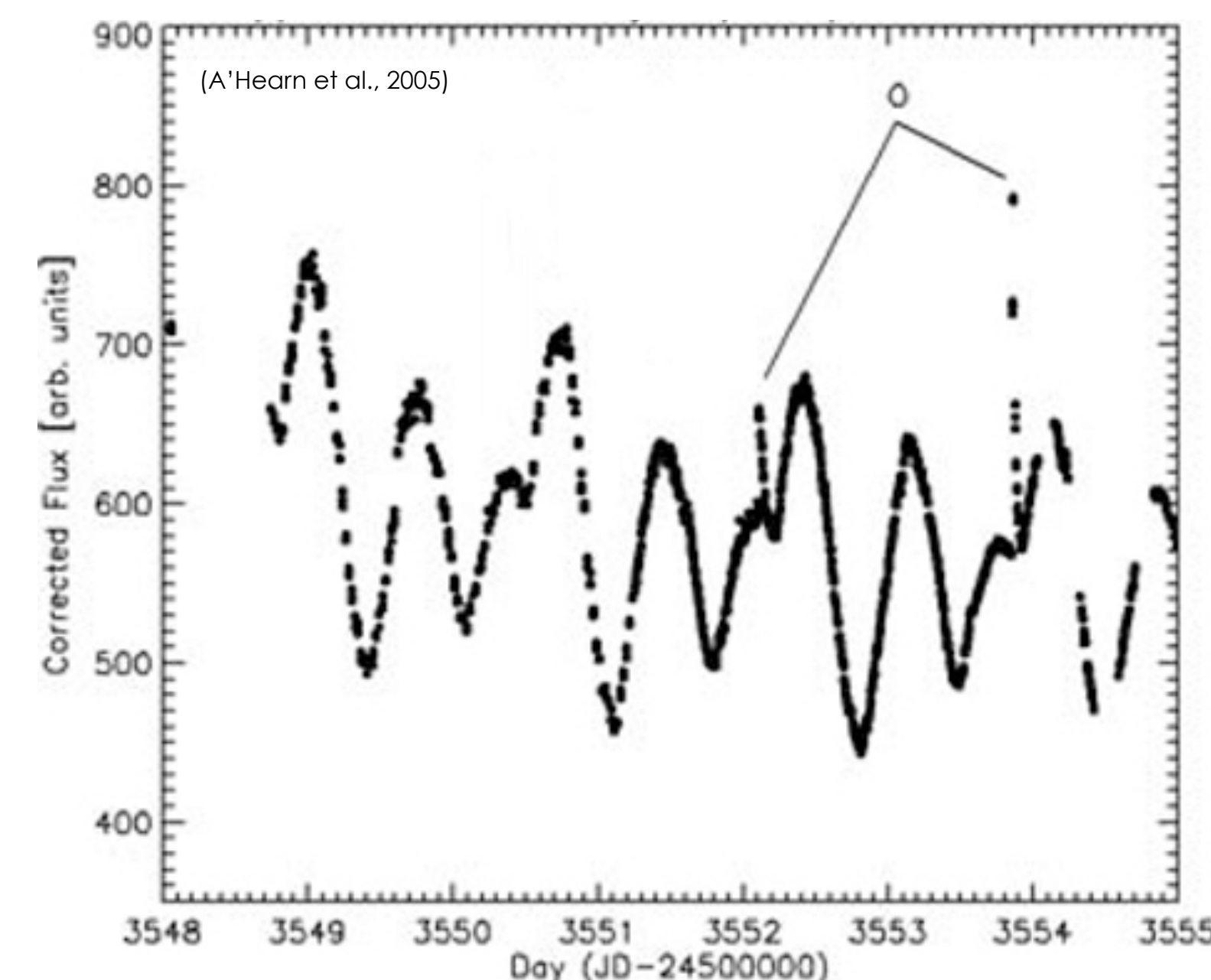


Fig. 5: Pre-impact photometry from Deep Impact that shows 2 outbursts occurring at similar rotational phases

Research Goals

- Use HRI-IR spectra to determine if/how the composition of the coma changes due to an outburst
- Determine the spatial distribution of volatiles before and after the outburst
- Make inferences about the cause of outbursts and comets in general

Data

Scan ID	Time relative to Outburst
8600000	-2.5 hours
8600001	-0.5 hours
8600002	+1.5 hours
8600003	+3.5 hours

Each scan consists of 50 8-second frames and was acquired in unbinned full frame mode. The comet is located inside the ASF for these data.

Data Reduction

- A spectrum is created by either totaling or averaging the spectra from different spatial coordinates
- Each spectrum is fitted with a continuum, which is modeled using a smoothed solar spectrum and a Plank function (numerous solutions are tested and a chi-squared test determines the best fit)
- Once the continuum is subtracted, emission bands can be integrated over and converted to the number of molecules in the field of view

Initial Results

- The abundance of H₂O remains essentially unchanged
- The abundance of CO₂ remains unchanged at ~10% relative to H₂O
- A strong emission band at 3.6 microns was detected only immediately after the outburst and was interpreted as formaldehyde, H₂CO
- The bulk H₂CO to H₂O ratio was calculated to be ~20% after the outburst

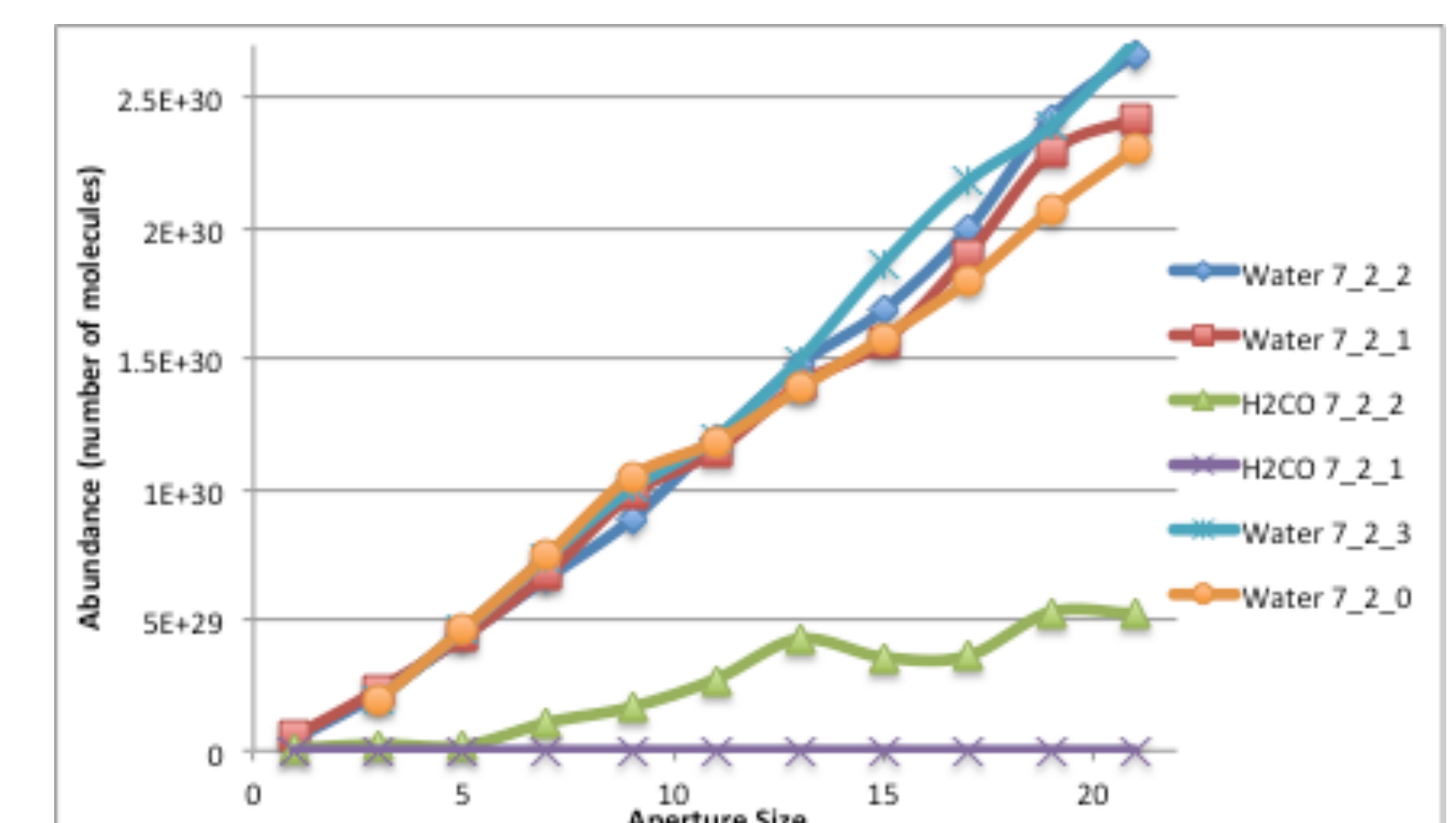


Fig. 6: Comparison of pre and post outburst abundances for water and H₂CO with respect to aperture size

Spatial Distribution of Volatiles

- H₂O may be enhanced in the direction of the outburst
- H₂O likely continued to sublime from the site of the outburst for at least 3.5 hours
- CO₂ did not show any hint of being associated with the outburst
- H₂CO appears to be strongly correlated with the outburst
- Regions associated with the outburst have an H₂CO to H₂O ratio of 30-60%
- For comparison, H₂CO was detected after the man-made impact at a ratio to H₂O less than 1%, which is consistent with the quiescent abundance of H₂CO at other comets

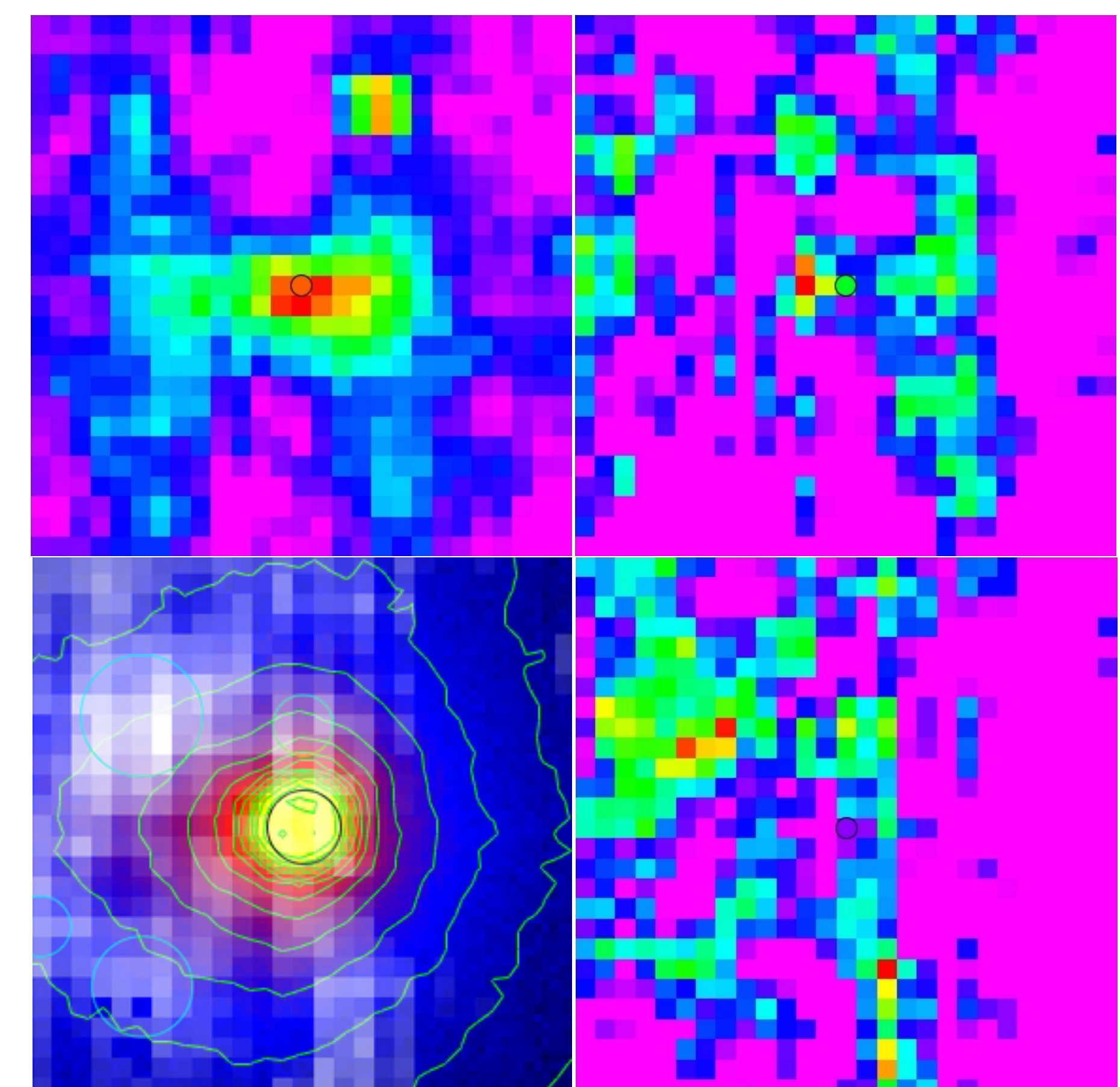


Fig. 7: Clockwise from top left: The spatial distributions of H₂O vapor, CO₂, and H₂CO. The bottom left frame shows the distribution of H₂CO superimposed on a portion of a visible light image taken shortly before the scan was acquired. The sun is to the right in each image and the scale is linear, though not the same in each frame. The visible image has a log scale. The black circles represent the location of the nucleus.

Acknowledgment

This work was funded through the Planetary Data System Student Investigators program. All Deep Impact data are freely available on the Planetary Data System.

Conclusions

- H₂CO is strongly associated with the July 2nd outburst at comet Tempel 1, both spatially and temporally. Many methods of analyzing the data yield consistent results, which lends credence to the detection.
- Our calculated H₂CO abundances are very large, an order of magnitude greater than any known previous detection. It is possible that errors in the calibration of the data can enhance, but not likely create, these results.
- H₂O and CO₂ do not drive this outburst as shown by their identical abundances pre and post-outburst.
- Due to its high abundance and behavior, it is likely that H₂CO propelled, or played a large part in propelling the July 2nd outburst.

Ongoing Work

- Investigation into how imperfections in calibration can affect the measured abundance of H₂CO
- Theoretical work and literature review into the formation and abundance of H₂CO in comets and the early Solar System as well as its ability to propel an outburst
- Searching for H₂CO in other Deep Impact data



Fig. 4: Tempel 1 post-impact

Data Calibration

- Data are decompressed, if needed
- Linearity coefficients are applied
- A master dark frame is scaled and subtracted
 - If possible a dark frame was constructed from the last 5 frames in a scan
 - If an in-scene dark (ISD) was used, the scaling factor was 1.0
- A flat-field is divided out to correct for pixel to pixel variations in sensitivity
- Our flat-field also corrects for the transmission profile of the ASF
- Data were converted to radiance units and a wavelength value was assigned to each pixel